NATIONAL HURRICANE CENTER TROPICAL CYCLONE REPORT

HURRICANE IRMA

(AL112017)

30 August–12 September 2017

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30 June 2018[1]

VIIRS SATELLITE IMAGE OF HURRICANE IRMA WHEN IT WAS AT ITS PEAK INTENSITY AND MADE LANDFALL ON BARBUDA AT 0535 UTC 6 SEPTEMBER.

Irma was a long-lived Cape Verde hurricane that reached category 5 intensity on the Saffir-Simpson Hurricane Wind Scale. The catastrophic hurricane made seven landfalls, four of which occurred as a category 5 hurricane across the northern Caribbean Islands. Irma made landfall as a category 4 hurricane in the Florida Keys and struck southwestern Florida at category 3 intensity. Irma caused widespread devastation across the affected areas and was one of the strongest and costliest hurricanes on record in the Atlantic basin.

[1] Original report date 9 March. Second version on 30 May updated casualty statistics for Florida, meteorological statistics for the Florida Keys, and corrected a typo. This version corrects the year of the last category 5 hurricane landfall in Cuba and corrects a typo in the Casualty and Damage Statistics section.

Hurricane Irma

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SYNOPTIC HISTORY

Irma originated from a tropical wave that departed the west coast of Africa on 27 August. The wave was then producing a widespread area of deep convection, which became more concentrated near the northern portion of the wave axis on 28 and 29 August. By 0000 UTC 30 August, satellite images indicated that a well-defined surface circulation had developed and since deep convection was already sufficiently organized, it is estimated that the system became a tropical depression at this time when it was centered about 120 n mi west-southwest of São Vicente in the Cabo Verde Islands. Banding features increased after genesis, and the depression became a tropical storm 6 h later. The "best track" chart of Irma's path is given in Fig. 1, with the wind and pressure histories shown in Figs. 2 and 3, respectively. The best track positions and intensities are listed in Table 1[2].

While moving westward to the south of a mid-level ridge over the eastern Atlantic, Irma strengthened rapidly in environmental conditions of low vertical wind shear and a fairly moist lower troposphere while it was over marginally warm sea surface temperatures (SSTs). Irma developed a ragged eye around the time it became a hurricane near 0600 UTC 31 August, which was only 30 h after it became a tropical depression. Irma reached hurricane strength when it was still located over the eastern Atlantic about 400 n mi west of the Cabo Verde Islands. Later on 31 August, Irma turned west-northwestward as the ridge to the north of the cyclone weakened a little. Meanwhile, Irma continued to rapidly strengthen, and it reached major hurricane status (>= 100 kt) by 0000 UTC 1 September, only two days after genesis. This 70-kt increase in intensity over a 48-h period is a remarkable rate that is only achieved by a small fraction of Atlantic tropical cyclones (about 1 in 30). Although Irma was a very intense hurricane at this time, the inner core was quite compact with hurricane-force winds estimated to extend no more than 15 n mi from the center (Fig 4).

After becoming a category 3 hurricane, Irma's intensification paused with the eye occasionally becoming cloud filled and deep convection in the eyewall appearing less intense. Irma fluctuated between category 2 and 3 strength from 0000 1 September to 0000 UTC 4 September. The main causes for the intensity fluctuations were likely eyewall replacement cycles and intrusions of dry air. Meanwhile, the hurricane turned west-southwestward in response to a strong high pressure system to its north (Fig 5a), and lost 2.5° of latitude between 2 and 4 September. This south of west motion was very significant because it brought the cyclone over higher SSTs and in a position poised to affect the northern Leeward Islands.

[2] A digital record of the complete best track, including wind radii, can be found on line at ftp://ftp.nhc.noaa.gov/atcf. Data for the current year's storms are located in the *btk* directory, while previous years' data are located in the *archive* directory.

Enclosure (14)

By early on 4 September, Irma's eye was growing in size and becoming better defined, and deep convection around the eye was gaining symmetry. Irma was on a strengthening trend once again, likely due to the completion of an eyewall replacement cycle, and it was headed toward the northern Leeward Islands. Irma turned west-northwestward, due to the erosion of the western side of the mid-level ridge (Fig 5b), and went through another round of rapid intensification. The hurricane reached its maximum intensity of 155 kt around 1800 UTC 5 September, when it was located about 70 n mi east-southeast of Barbuda. As a category 5 hurricane, Irma made landfall on Barbuda around 0545 UTC 6 September with maximum winds of 155 kt and a minimum pressure of 914 mb (Fig. 6a).

After crossing Barbuda, Irma continued to exhibit an impressive satellite appearance and made its second landfall on St. Martin at 1115 UTC that day, with the same wind speed and pressure as for its Barbuda landfall. Still moving west-northwestward to the south of a mid-level ridge, Irma made its third landfall on the island of Virgin Gorda in the British Virgin Islands at 1630 UTC 6 September still as a 155-kt category 5 hurricane. Later that day, as Irma moved away from the Virgin Islands, reconnaissance data from the Air Force indicated that the major hurricane had weakened slightly and had a double wind maximum, indicative of concentric eyewalls. The double eyewall structure was also evident in Doppler radar data from San Juan, Puerto Rico (Fig. 7). Even though Irma was no longer at its peak intensity, it remained a category 5 hurricane with a larger wind field than it had previously (Fig. 4). The eye of Irma tracked about 50 n mi to the north of the northern shore of Puerto Rico and the Dominican Republic from 1800 UTC 6 September to 1800 UTC 7 September, with the strongest winds to the north of the center.

The eye of Irma passed just south of the Turks and Caicos Islands around 0000 UTC 8 September, and it made landfall on Little Inagua Island in the Bahamas at 0500 UTC that day at category 4 intensity, with estimated maximum winds of 135 kt and a minimum pressure of 924 mb. This slight weakening ended Irma's 60-h period of sustained category 5 intensity, which is the second longest such period on record (behind the 1932 Cuba Hurricane of Santa Cruz del Sur). Irma then turned slightly to the left, due to a building subtropical ridge, and moved toward the northern coast of Cuba (Fig. 5c). Reconnaissance and microwave data indicate that the inner core had become better organized, and it is estimated that Irma strengthened to a category 5 hurricane again around 1800 UTC 8 September, only 18 h after weakening below that threshold.

Irma then intensified a little more and made its fifth landfall near Cayo Romano, Cuba, at 0300 UTC 9 September, with estimated maximum winds of 145 kt (Fig. 6b). This marked the first category 5 hurricane landfall in Cuba since Huracan sin Precedentes in 1924. Irma tracked along the Cuban Keys throughout that day, and its interaction with land caused it to weaken significantly, first to a category 4 storm a few hours after landfall in the Cuban Keys and then down to a category 2 hurricane by 1800 UTC that day when the eye was very near Isabela de Sagua. Shortly after that time, the forward speed of Irma slowed, and it began to make a turn to the northwest, which caused the core of the hurricane to move over the Florida Straits early on 10 September.

When Irma moved over the warm waters of the Florida Straits, the hurricane reintensified once again. Data from the Air Force Hurricane Hunters indicate that Irma became a category 4 hurricane by 0600 UTC 10 September when it was centered about 55 n mi south-southeast of Key West, Florida. Meanwhile, Irma had turned to the north-northwest in the flow between a subtropical ridge over the western Atlantic and a mid- to upper-level low pressure system over the Gulf of Mexico (Fig 5d). The category 4 storm made yet another landfall near Cudjoe Key in

the lower Florida Keys around 1300 UTC that day with maximum winds of 115 kt and a minimum pressure of 931 mb (Fig 6c).

The convective pattern of the hurricane then became more ragged, likely due to increasing southwesterly vertical wind shear, and in response, Irma weakened to a category 3 hurricane around 1800 UTC 10 September. Irma made its final landfall near Marco Island, Florida, at 1930 UTC 10 September (Fig. 6d), with estimated maximum winds of 100 kt and minimum pressure of 936 mb. Once inland over southwestern Florida, Irma weakened quickly, due to the influences of land and strong wind shear, while moving north-northwestward on the east side of a large cyclonic gyre that was centered over the Gulf of Mexico. Irma's center tracked just east of Naples and Ft. Myers by 0000 UTC 11 September as a category 2 hurricane and passed between Tampa and Orlando by 0600 UTC that day as a category 1 storm. Although Irma was weaker while over Florida, the wind field of the hurricane spread out significantly, with tropical-storm-force winds extending up to 360 n mi from the center (Fig. 4).

Irma weakened to a tropical storm by 1200 UTC 11 September when it was centered about 20 n mi west of Gainesville, Florida. While Irma was moving across northern Florida, most of the deep convection was located well to the northeast of the center, and the strongest winds were confined to the northeast coast of Florida and southeastern Georgia. The center of Irma moved over southern Georgia just west of Valdosta around 1800 UTC that day with maximum winds of 45 kt, and the system became a remnant low with 25-kt winds once it crossed into Alabama by 0600 UTC 12 September. The remnant low continued northwestward while weakening and dissipated shortly after 1200 UTC 13 September over southeastern Missouri.

METEOROLOGICAL STATISTICS

Observations in Irma (Figs. 2 and 3) include subjective satellite-based Dvorak technique intensity estimates from the Tropical Analysis and Forecast Branch (TAFB) and the Satellite Analysis Branch (SAB), and objective Advanced Dvorak Technique (ADT) estimates from the Cooperative Institute for Meteorological Satellite Studies/University of Wisconsin-Madison. Data and imagery from NOAA polar-orbiting satellites including the Advanced Microwave Sounding Unit (AMSU), the NASA Global Precipitation Mission (GPM), the European Space Agency's Advanced Scatterometer (ASCAT), and Defense Meteorological Satellite Program (DMSP) satellites, among others, were also useful in constructing the best track of Irma.

Aircraft observations include flight-level, stepped frequency microwave radiometer (SFMR), and dropwindsonde observations from 15 flights (including 56 center fixes) of the 53rd Weather Reconnaissance Squadron of the U.S. Air Force Reserve Command and 8 flights (including 26 center fixes) of the NOAA Aircraft Operations Center (AOC). In addition, the NOAA AOC G-IV aircraft flew 8 synoptic surveillance flights around Irma.

National Weather Service WSR-88D Doppler radar data from San Juan, Puerto Rico; Miami, Florida; Key West, Florida; Melbourne, Florida; Jacksonville, Florida; Tampa, Florida; and Tallahassee, Florida, were used to make center fixes and obtain velocity data while Irma was

near the U. S. coast. Météo-France radar data from Guadeloupe and Martinique as well as radar data from the Institute of Meteorology of Cuba were also helpful in tracking the center of Irma.

Selected ship reports of winds of tropical storm force or greater associated with Irma are given in Table 2, and selected surface observations from land stations and data buoys are given in Table 3.

Winds and Pressure

Irma's estimated peak intensity of 155 kt from 1800 UTC 5 September to 1200 UTC 6 September is based on a blend of multiple SFMR surface wind estimates and flight-level winds observed by the Air Force Reserve and NOAA Hurricane Hunters during that time period. The highest unflagged SFMR surface wind estimate from the Air Force Reserve was 160 kt at 1633 UTC 5 September. The flight-level winds measured during that mission were around the same speed. The peak 700-mb flight-level winds of 164 kt, which correspond to a peak surface wind of 145–150 kt, were measured by the Air Force Reserve early on 6 September. The NOAA Hurricane Hunters measured maximum 750-mb flight-level winds of 167 kt, which correspond to about 150 kt at the surface, and peak SFMR winds of 152 kt. It should be noted that this intensity estimate is somewhat uncertain given the disparity between the peak SFMR winds and the intensity supported by the highest flight-level winds. The 155-kt peak intensity of Irma is 5 kt lower than the operational assessment in favor of blending the flight-level and SFMR reports.

Irma's estimated minimum central pressure of 914 mb at 0600 UTC 6 September is based on a dropwindsonde surface pressure measurement of 915 mb at 0503 UTC 6 September, which was accompanied by a surface wind of 15 kt. This estimate is also consistent with a weather station on St. Barthelemy that reported a minimum pressure of 915.9 mb, and a station on Barbuda that reported a minimum pressure of 916.1 mb. The Barbuda station reported sustained winds of 105 kt and a gust of 139 kt when it was in the southern eyewall. Also, an unofficial observation in St. Barthelemy reported a maximum wind gust of 173 kt.

Caribbean Islands

Around 1700 UTC 6 September, the center of Irma passed just north of Buck Island in the U.S. Virgin Islands, where sustained winds of 92 kt and a gust of 119 kt were reported.

Irma's center passed about 50 n mi north of San Juan, Puerto Rico, just before 0000 UTC 7 September. The lowest pressure observed on mainland Puerto Rico during Irma was from a National Ocean Service (NOS) station in Fajardo, which recorded a pressure of 980.1 mb at 2118 UTC 6 September. The highest wind speed reported in Puerto Rico was 48 kt with a gust of 64 kt at an NOS site at La Puntilla in San Juan Bay at 2230 UTC 6 September.

The Turks and Caicos Islands experienced the northern eyewall of Hurricane Irma around 0000 UTC 8 September. However, no observations were available from these locations due to failure of the observing equipment.

The hurricane then took a long duration track along or near the northern coast of Cuba from 8 September through early 10 September. Irma approached the northern coast of eastern Cuba late on 8 September, with sustained 10-minute winds of 44 kt and a peak gust of 63 kt observed in the town of Velasco at 1959 UTC. The lowest pressure recorded on land that day

was 991.0 mb at 2100 UTC in La Jiquima, Holguin. Irma tracked near or over the Cuban Keys on 9 September and, at 1430 UTC, a coastal station at Caibarien recorded sustained winds of 85 kt with an accompanying gust of 122 kt, and a minimum pressure of 969.9 mb when Irma's center passed approximately 15 n mi northeast of that location. The lowest recorded pressure in Cuba during Irma was 933.1 mb at Cayo Coco at 0520 UTC 9 September, which was in the eye of the hurricane at that time. The western eyewall was also sampled at that station, with sustained winds of 83 kt and a gust of 105 kt observed at 0500 UTC that day. The highest wind speed recorded in Cuba was just inland of Cayo Coco at a station near Camilo, Cienfuegos, where sustained winds of 108 kt and a gust of 138 kt were measured at 0720 UTC 9 September. Early on 10 September, Irma departed the coastal region of central Cuba as it turned north-northwestward toward Florida. Tropical storm conditions continued over a portion of Cuba that day, with sustained winds of 49 kt and a gust of 73 kt observed at San Antonio de los Banos. Although observations were not available from Havana, two observations recorded tropical-storm-force winds just southeast of the capital city.

United States

The earliest significant report of high winds in Florida came from an observation at Alligator Reef Light at 1159 UTC 10 September, where sustained winds of 62 kt and a gust of 81 kt were measured. At 1204 UTC that day, a minimum pressure of 977.0 mb was recorded at that same station when the center of Irma was nearly 50 n mi to its west-southwest. The lowest pressure reported in the Florida Keys was 933.7 mb at 1216 UTC by a spotter in Big Pine Key. The strongest wind speed in the Florida Keys was reported by an automated station on Big Pine Key, where a 104-kt gust at an observing site of 6 meter elevation was recorded (10 m is standard height).

Irma made its final landfall near Marco Island, Florida, at 1930 UTC 10 September. A spotter in Marco Island reported a minimum pressure of 936.9 mb, with maximum sustained winds of 97 kt and a gust of 112 kt. In addition, the Marco Island Police Department reported a wind gust of 113 kt at 1900 UTC, and the Naples Municipal Airport reported a 123-kt wind gust around the same time. Sustained hurricane force winds extended well inland over the southern Florida peninsula. At Government Cut off of Miami Beach sustained winds of 65 kt at an elevation of 23 meters occurred, and a wind gust of 97 kt was measured at Deerfield Beach. Nearly all of the inland observations in the Miami-Dade and Broward County metro area reported sustained winds just below hurricane force. At 1903 UTC that day, the Opa Locka Airport reported 2-minute averaged sustained winds of 56 kt with a gust of 74 kt, and several other nearby stations reported similar wind speeds.

The hurricane continued northward across central Florida with hurricane conditions decreasing in areal coverage when Irma's center approached the Orlando and Tampa areas. Tropical storm conditions were experienced on both the west and east coasts of the state on 10 and 11 September. The center passed near Plant City at 0509 UTC 11 September, where a spotter reported a minimum pressure of 964.4 mb. At 0142 UTC, a couple of hours before the eyewall and strongest winds arrived, that spotter measured 10-second 7-meter winds of 63 kt and a gust to 71 kt. Reports from both sides of the state confirmed Irma's expansive wind field. For example, buoy 42036 offshore of Tampa in the Gulf of Mexico measured 44 kt sustained winds at 5-meters with a 10-min averaging period at 0420 UTC 11 September. Also in the Gulf of Mexico, at 0823 UTC that day, buoy 42039 offshore of Pensacola measured 37 kt sustained winds

at an elevation of 4 meters. Off the east coast, buoy 41009 off of Cape Canaveral measured sustained winds of 56 kt at 4 meters.

Irma moved across north-central Florida through early 11 September and then moved into southeastern Georgia late that day and early 12 September. Tropical storm conditions were reported across much of northern Florida, especially to the east of the center. The Jacksonville International Airport measured sustained 2-minute 10-meter winds of 51 kt at 1053 UTC 11 September with a gust of 75 kt. At the Gainesville Regional Airport, closer to where the center passed, a minimum pressure of 979.5 mb was observed at 1053 UTC with maximum sustained 2-minute 10-meter winds of 40 kt.

Several sites in Georgia and South Carolina reported tropical storm conditions from Irma on 11 September. These reports include locations as far north as the Atlanta International Airport, which measured 2-minute 10-meter winds of 39 kt at 1910 UTC and a gust of 56 kt. At 1609 UTC, Charleston International Airport in South Carolina measured 2-minute 10-meter winds of 42 kt and a gust of 52 kt.

Figure 8 shows observed maximum sustained wind speeds during Hurricane Irma for Cuba and portions of the southeastern United States, and Fig. 9 show maps of maximum wind gusts for the same geographical areas.

Landfall Intensity Estimates

Barbuda: The estimated landfall intensity of 155 kt at 0545 UTC 6 September is based on a blend of SFMR surface wind values near 160 kt and flight-level winds of 161 kt, which reduce to about 145 kt at the surface, measured by the Air Force Hurricane Hunters around the time of landfall. The lowest pressure observed in Barbuda was 916.1 mb.

St. Martin: The estimated landfall intensity of 155 kt at 1115 UTC 6 September is based on similar data to the Barbuda landfall with SFMR values around 155 kt.

British Virgin Islands: The estimated landfall intensity of 155 kt at 1630 UTC 6 September on Virgin Gorda is based on SFMR winds around 155 kt.

Bahamas: The estimated landfall intensity of 135 kt on Little Inagua Island at 0500 UTC 8 September is based on flight-level winds reported by the Air Force of 147 kt, which reduce to 132 kt at the surface, and an ADT estimate of 7.0/140 kt.

Cuba: The estimated landfall intensity of 145 kt near Cayo Romano at 0300 UTC 9 September is based on SFMR winds of 145 kt measured by the Air Force a few hours before landfall.

Florida Keys: The estimated landfall of 115 kt at 1300 UTC 10 September near Cudjoe Key is based on SFMR winds between 110 and 120 kt just prior to landfall.

Southwest Florida: The estimated landfall intensity of 100 kt at 1930 UTC 10 September near Marco Island is based on a sustained surface wind measurement of 97 kt from a nearby weather spotter.